7.Wave Optics

Define wave optics :

The branch of optics which uses wave nature of light to explain the optical phenomena is called wave optics.

What is meant by primary and secondary source of light :-

Primary Source of Light :

The source that emits light of its own is called primary source of light.

Emission of light is due to -

1) High temperature (Ex. Sun)

2) Effect of electric current (Ex. Tube light)

3) Chemical or nuclear reaction. (Ex. Firecrackers, Nuclear generator)

Secondary Source of Light :

The source that does not emit light of its own but reflect or scatter the light from the primary source, is called secondary source

of light.

Ex. Planets, moon, objects like humans, plants, animals etc.

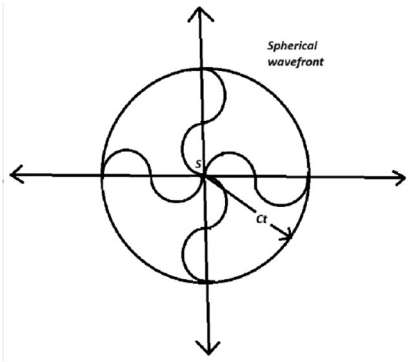
Explain the dual nature of light?

Ans.:- The dual nature of light means that light behaves like waves as well as the particles. The wave nature is useful in explaining the phenomenon like diffraction, interference, and polarisation etc. The particle nature is useful in explaining the phenomenon like photoelectric effect, Compton effect etc.

Wave Front :

Define : The locus of all the points of medium, to which the waves reach simultaneously, so that all the points are in same phase, is known as wavefront.

Consider a point source S of light, which emits the waves in all direction. If C is the velocity of light, then each wave travels a distance ct in time t. Then the radius of the wavefront is ct.



Wave Normal :

Define : A perpendicular drawn to the surface of wavefront at any point in the direction of propagation of light is called as the wave normal.

Ray of light :

Define : The direction in which the light waves travels, is known as the ray of light.

Types of Wavefronts :

1) Plane wavefront :

At large distance from the point source of light, the spherical wavefront is so large, that a small part of this wavefront becomes plane, which is called a plane wavefront.

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2) Spherical wavefront :

The wavefront which is originated from the point source of light, is called as the spherical wavefront.

3) Cylindrical wavefront :

The wavefront which is originated from a source, in the form of long, narrow slit, is called as the cylindrical wavefront.

Huygen's Principle :

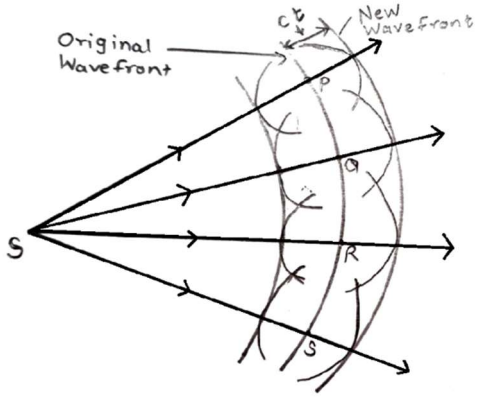
Statement : It states that, "Each and every point on the wavefront acts as a secondary source of light and emits the light waves in forward direction with the same speed as that of the speed of the original wave."

OR

1) Statement : Every point on the wavefront acts as a secondary source of light and gives secondary waves in all possible directions.
2) The new secondary wavelets are more effective in the forward direction only.
3) The resultant wavefront at any position is given by the tangent to all the secondary wavelets at that instant.

Construction of spherical wavefront :

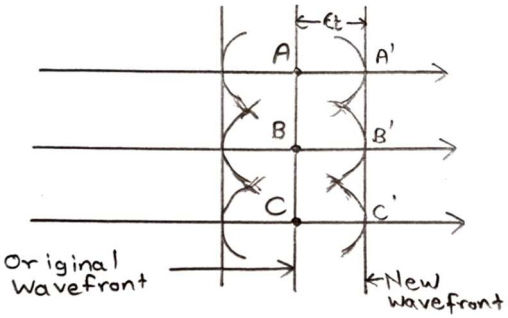
Consider a spherical wavefront PQRS originated from a point source S. According to Huygen's principle each point like P,Q,R & S acts as a secondary source of light and will starts emitting the secondary waves in all directions. Hence each point gives rise to a spherical wavefront of radius ct after time t. To determine the position of new wavefront, draw the spheres of radius ct with P,Q,R & S as the centres. Then the tangential surface P'Q'R'S' to these spheres represents the new wavefront after time t. It is also a spherical wavefront.



Construction of plane wavefront :

Consider a plane wavefront ABC at time t = 0. Let the wavefront is moving with velocity C. According to Huygen's principle every point on the wavefront like A,B & C acts as a secondary source of light and starts emitting the secondary waves. Therefore, each point gives rise to a spherical wavefront of radius ct after time t.

To determine the position of new wavefront, draw the spheres of radius ct, with A,B & C as the centres. Then the tangential surface to these spheres A'B'C' represents the new wavefront after time t It is also a plane wavefront.



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Reflection of Plane wavefront at plane surface:-

[With neat labelled diagram, explain the reflections of light on the basis of wave theory of light . OR Show that angle of incidence is equal to angle of reflection on the basis of wave theory of light]

AB → Incident wavefront

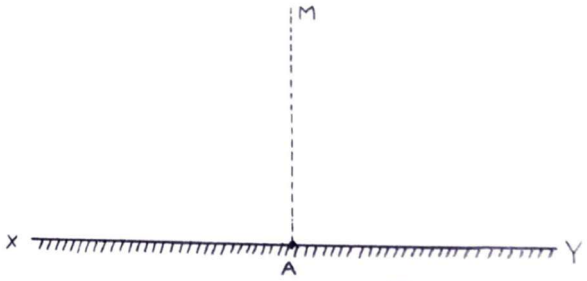
CD → Reflected wavefront

MA → Normal

XY → Plane reflecting surface

$\angle i \rightarrow$ Angle of incidence

$\angle r \rightarrow$ Angle of reflection



Let xy be the plane reflecting surface on which a plane wave front bounded by two parallel rays PA & QB is incident.

As soon as the wave front reaches at point A, it acts as a secondary source & emits the secondary wares.

Let the incident wavefront moves from B to C in time t.

$$\therefore BC = ct \quad \text{, Where c is the velocity of light}$$

During the same time t, the secondary waves from A will travels a distance ct in time t .

$$\therefore AD = ct$$

Now taking A as a centre & ct as a radius , draw the semicircle. Then the tangential surface CD represents the reflected wave front.

Let $\angle PAM = \angle i \rightarrow$ Angle of incidence

Let $\angle MAD = \angle r \rightarrow$ Angle of reflection

In ΔABC and ΔADC

$\therefore BC = AD = Ct$

$\therefore AC = AC =$ common side

$\therefore \angle ABC = \angle ADC = 90^0$

$\therefore \Delta ABC$ is congruent to ΔADC

$\therefore \angle BAC = \angle DCA$ _____(i)

corresponding angles of corresponding triangles.

Hence $\angle BAC = \angle i$ and $\angle DCA = \angle r$

From eq^n (i)

$\therefore \angle i = \angle r$

Thus, the angle of incidence is equal to angle of reflection.

From figure, it is clear that the incident ray , reflected ray and the normal , lies in the same plane.

Principle Of Superposition of Waves :-

When two or more waves travelling through medium arrive at a point simultaneously, then each wave produces its own displacement at that point independently. So, the resultant displacement at that point is the vector sum of displacement due to all the waves , this is known as principle of superposition of waves.

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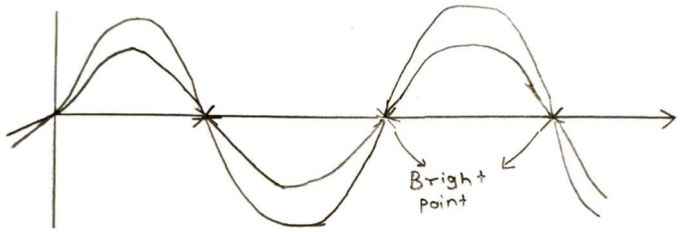
Interference of Light :-

When two light waves are travelling through a medium & arrive at a point simultaneously, then the intensity of light at that point is modified. Such a modification in intensity, due to superposition of light waves, is known as interference of light.

Constructive interference :-



When two light waves arriving at a point are in phase i.e., the crest of one wave fall on crest of another wave. Then the resultant displacement at that point is maximum. So, the intensity of light is maximum & the point appears bright . This type of interference is known as constructive interference .

Condition for constructive interference :-

When two interfering waves at a point are in phase , then that point appears as a bright point.

$\therefore$ Phase difference $= 0, 2\pi, 4\pi, 6\pi \ldots\ldots\ldots\ldots$

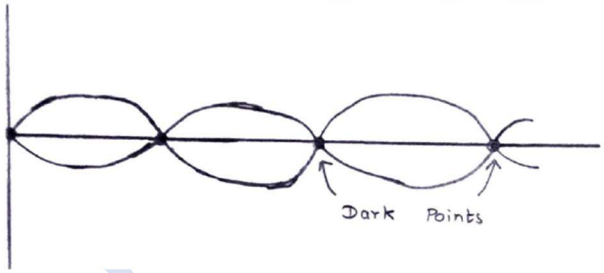
Path difference $= 0, \lambda, 2\lambda, 3\lambda \ldots\ldots\ldots\ldots\ldots$

$$= 0, \frac{2\lambda}{2}, \frac{4\lambda}{2}, \frac{6\lambda}{2} \ldots\ldots\ldots\ldots$$

Path difference $= 2n\left({}^{\lambda}/_{2}\right)$

Where n=0,1,2……

Destructive interference :-



When two light waves arrive at a point are out of phase i.e., crest of one wave fall on trough of other wave or vice-versa, then the resultant displacement at that point is minimum. So, the intensity of light is minimum & the point appears dark. This type of interference is called destructive interference.

Condition for Destructive Interference :-

When the two waves interfering at a point are out of phase, then the resultant point appears dark.

$\therefore$ Phase difference $= 0, 3\pi, 5\pi, 7\pi \ldots\ldots\ldots\ldots$

Path difference $= {}^{\lambda}/_{2}, {}^{3\lambda}/_{2}, {}^{5\lambda}/_{2} \ldots\ldots\ldots\ldots\ldots$

$$= (2n-1)\,{}^{\lambda}/_{2}$$

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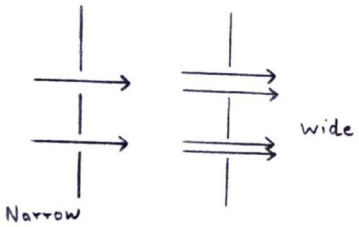
Where n=1,2…….

Conditions for Steady Interference pattern :-

1. The two sources of light must be Coherent:
   This condition can be satisfied by obtaining the two sources from single original source. It is necessary to obtain a steady interference pattern.
2. The two sources must be monochromatic :
   A source of light is monochromatic, if it emits the light waves of same wavelength. This is necessary to get the sharp & well-defined interference pattern. If the wavelength is not equal, then the interference pattern will be diffused (less sharp).
3. The two sources should be equally bright i.e. the amplitudes of waves emitted by sources must be equal :
   If the amplitudes are not equal, then the dark band will not completely dark & therefore clear interference pattern will not be observed.
4. The two sources must be narrow :
   If the two sources are not narrow, then instead of getting two waves, we get large number of waves. Due to this the interference pattern will be diffused so for getting clear & sharp interference pattern the two sources must be narrow.



5. The two sources of light should be close to each other :
   This condition is necessary to get sufficient separation between the regions of maximum & minimum intensity. Due wide separation between the sources, the bright & dark bands will not be observed clearly.
6. The direction of waves starting from the source must be same.
7. The two interfering waves must be in the same state of polarisation.
8. The distance of the screen from the two sources should be large.

Young's double slit experiment :

[Describe Young'sdouble slit expt. & state its importance ?]

Leave 15 lines for Diagram

Young's demonstrated the phenomenon of Interference of light He allows the Sunlight to fall on a pin hole S & then on two pin holes S_1 & S_2, which are separated by a small distance d & equidistant from S. Therefore, the pin holes S_1 & S_2, acts as a Coherent source as shown in figure.
The secondary waves from S_1 & S_2, interference with each other & on screen the interference bands are produced, which are alternately dark & bright. The points like B are bright, because Crest of one wave fall on Crest of another wave or trough of one wave fall on trough of other wave. The points like D are dark, because the crest of one wave fall on trough of other wave & vice-versa.

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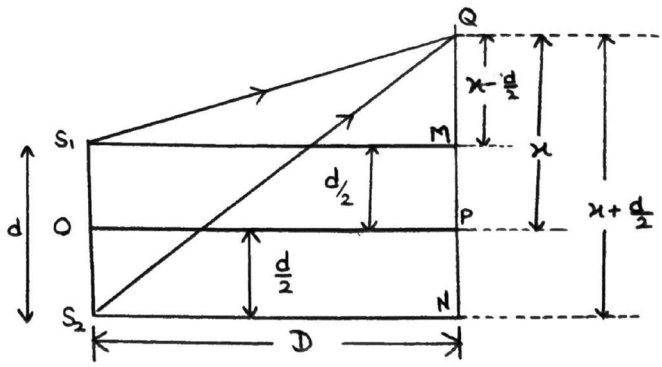
If instead of S_1 & S_2, two narrow slits parallel to each other & equidistant from S are used & which are illuminated by monochromatic light, then well spaced alternate bright & dark bands are obtained on the screen. These are also called as fringes. Hence a steady interference pattern can be obtained by the Young's double slit experiment.

Importance :-

1. It was the first expt. in which the interference of light was observed & hence the Historical importance.
2. It proves conclusively that the light is propagated in the form of waves.
3. Wavelength of light can be calculated by using this expt.

Theory of interference bands and expression for band width (fringe width) :

[Give the theory of interference bands show that the distance between two cosecutive bright bands is equal to the distance between two cosecutive dark bands ?]



Consider two coherent sources S_1 & S_2 which are separated by a small distance 'd'. The light waves emitted from S_1 & S_2 produces an interference pattern on screen, which is at a distance D from sources OP be the perpendicular bisector of MN. Now consider a point Q on the screen which is at a distance x from central band. Join S_1Q & S_2Q then the brightness & darkness of point Q depends upon the path difference ($S_2Q - S_1Q$).

The point Q will be bright if,

$$S_2Q - S_1Q = n\lambda \qquad \text{, where } n = 0,1,2,3 \dots\dots\dots\dots\dots$$

& The point Q will be dark if,

$$S_2Q - S_1Q = (2n-1)\frac{\lambda}{2} \qquad \text{, where } n - 1,2 \dots\dots\dots\dots\dots$$

1. **Expression for path difference :**

From fig, In $\triangle S_1MQ$

$$(S_1Q)^2 = (S_1M)^2 + (MQ)^2$$

$$= D^2 + (x - {}^{d}/_{2})^2 \qquad \text{_____(1)}$$

Now In $\triangle S_2NQ$

$$(S_2Q)^2 = (S_2N)^2 + (NQ)^2$$

$$= D^2 + (x + {}^{d}/_{2})^2 \qquad \text{_____(2)}$$

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$\therefore$ Substract equation (1) from (2)

$$(S_2Q)^2 - (S_1Q)^2 = \left[D^2 + \left(x + {}^{d}/_{2}\right)^2\right] - \left[D^2 + (x - {}^{d}/_{2})^2\right]$$

$$(S_2Q - S_1Q)(S_2Q + S_1Q) = D^2 + x^2 + xd + \frac{d^2}{4} - D^2 - x^2 + xd - \frac{d^2}{4}$$

$$(S_2Q - S_1Q)(S_2Q + S_1Q) = 2xd$$

$$(S_2Q - S_1Q) = \frac{2xd}{(S_2Q + S_1Q)}$$

Now the distances x & d are small as compared to distance D (i.e. $D \gg x$)

$\therefore S_1Q \cong S_2Q \cong D$

$\therefore$ path difference $(S_2Q - S_1Q) = \dfrac{2xd}{2D}$

$$\boxed{(S_2Q - S_1Q) = \frac{xd}{D}}$$

The point Q will be bright if,

$$\frac{xd}{D} = n\lambda$$

$$\boxed{x = \frac{n\lambda D}{d}} \quad \text{_____(3)}$$

Where n=0,1,2…….

& The point Q will be dark if,

$$\frac{xd}{D} = (2n-1)\frac{\lambda}{2}$$

$$\boxed{\therefore x = \frac{(2n-1)\lambda D}{2d}} \quad \text{_____(4)}$$

Where n=1,2,3……

$\therefore$ equation (3) & (4)gives the distance of bright & dark fringes from the central bright band.

2. Expression for Band width (X) or W :

Define : The distance between two consecutive bright or dark bands, is known as Band width or fringe width.

❖ For bright band :

Let x_n & x_{n+1} be the distance of n^{th} and $(n+1)^{th}$ bright bands from central band respectively.

$\therefore from\ equation\ (3)$

$$x_n = \frac{n\lambda D}{d} \quad \& \ x_{n+1} = \frac{(n+1)\lambda D}{d}$$

$$\therefore Band\ width\ (X) = x_{n+1} - x_n$$

$$= \frac{(n+1)\lambda D}{d} - \frac{n\lambda D}{d}$$

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$$= \frac{\lambda D}{d} [\, n + 1 - n$$

$$W = X = \frac{\lambda D}{d} \text{ _____} (5)$$

❖ For dark band :

Let x_n & x_{n+1} be the distance of n^{th} and $(n+1)^{th}$ dark bands from central band respectively.

$\therefore from\ equation\ (4)$

$$x_n = \frac{(2n-1)\lambda D}{2d}$$

$$x_{n+1} = \frac{[2(n+1)-1]\lambda D}{2d}$$

$$x_{n+1} = \frac{(2n+1)\lambda D}{2d}$$

$$\therefore Band\ widh\ (X) = x_{n+1} - x_n$$

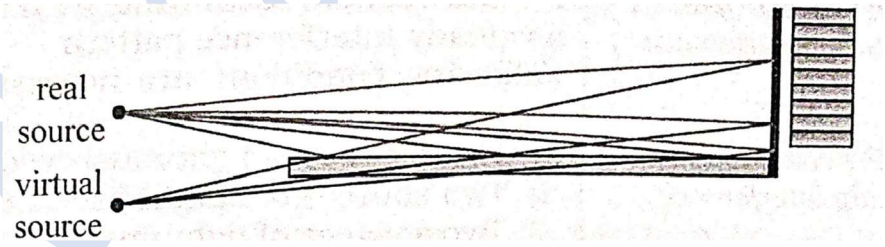
$$= \frac{(2n+1)\lambda D}{2d} - \frac{(2n-1)\lambda D}{2d}$$

$$= \frac{\lambda D}{2d} [\, 2n + 1 - 2n + 1]$$

$$\boxed{W = X = \frac{\lambda D}{d}} \text{ _____} (6)$$

From equation (5) & (6) it is clear that, the distance between two consecutive bright bands is equal to the distance between two consecutive dark bands. Thus, the bright & dark bands are alternate & Equi spaced in the interference pattern.

a) Method for Obtaining Coherent Sources Using Lloyd's Mirror



i. In this method the light from a source is made to fall at a grazing angle on a plane mirror.
ii. Some of the light falls directly on the screen (shown by solid lines) and some light falls after reflection (shown by dotted lines).
iii. The reflected light appears to come from a virtual source and thus there are two sources.
iv. The two sources are coherent as they are derived from the same source.
v. Waves from two sources interfere and interference pattern is obtained.

b) Method for Obtaining Coherent Sources Using Fresnel Biprism

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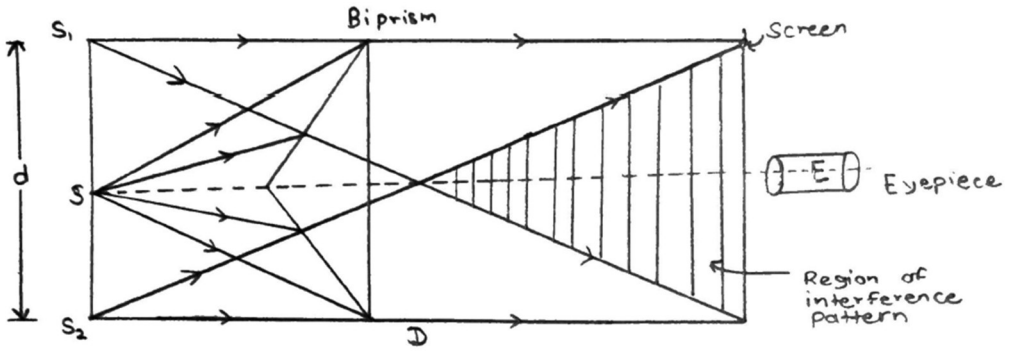

i. In this method, the refracting edge of the biprism is kept parallel to the length of the slit.
ii. Monochromatic light from a source is made to pass through a narrow slit S and fall on the biprism having vertex angle of nearly 180°.
iii. The two halves of the biprism form virtual images S_1 and S_2 which act as coherent sources because they are obtained from the same source.
iv. Waves from two sources interfere and interference pattern is obtained.

Optical Path

Optical path through a medium is the effective path travelled by light in vacuum to generate the same phase difference.

Explanation

1) Consider a light wave having angular frequency ω and wave vector k, travelling in vacuum along x-direction. If it travels a distance $\triangle x$, its phase changes by –

$$\triangle \Phi = k \triangle x = \frac{\omega \Delta x}{c} \ldots\ldots\ldots\ldots\ldots \{\because k = \frac{\omega}{c}\}$$

Where c is the speed of wave in vacuum.

If the wave having wave vector k' is ravelling in a medium having a refractive index n, its phase difference is given by-

$$\triangle \Phi' = k' \triangle x = \frac{\omega n \Delta x}{c} \ldots\ldots\ldots\ldots\ldots \{\because k' = \frac{\omega n}{c}\}$$

$$\therefore \Delta\Phi = \mathrm{n}\Delta\Phi$$

Thus, when a wave travels a distance $\triangle x$ through a medium having refractive index n, its phase changes by the same amount as it would if the wave had travelled a distance $n \triangle x$ in vacuum. This $n \triangle x$ is the optical path.

2) For vacuum, n=1

$\therefore$ optical path $=$ actual path travelled

3) Optical path is the corresponding path in vacuum that the light travels in the same time as it takes in the given medium.

We have,

$$time = \frac{distance}{speed}$$

$$\therefore \mathrm{t} = \frac{\mathrm{d_{medium}}}{\mathrm{v_{medium}}} = \frac{\mathrm{d_{vacuum}}}{\mathrm{v_{vacuum}}}$$

$$\therefore optical\ path\ (\mathrm{d_{vacuum}}) = \frac{\mathrm{v_{vacuum}}}{\mathrm{v_{medium}}} \times \mathrm{d_{medium}}$$

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$\therefore optical\ path = n \times \mathrm{d}_{\mathrm{medium}}$

Diffraction :

[Define diffraction ? What are the types of diffraction]

Define: The phenomenon of bending of light around the corners of an obstacle or an aperture into region of geometrical shadow of obstacle is called diffraction of light.

Diffraction of light is of two types,

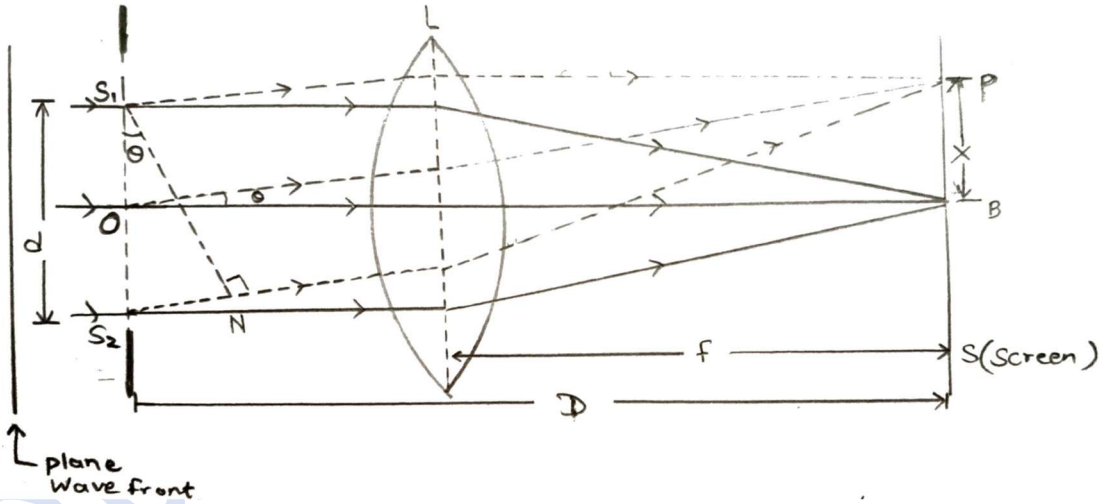
(1) Fresnel diffraction
(2) Fraunhoffer diffraction

i) Fresnel diffraction : When the source of light & screen are at finite distance from the slit, the diffraction produced is known as Fresnel diffraction.
As the source of light is closed to the slit the incident wavefront is not a plane wavefront.

ii) Fraunhoffer diffraction : When the source of light & screen are at infinite distance from the slit, the diffraction produced is known as Fraunhoffer diffraction.
As the source of light & screen are at infinite distance from the slit, the incident wavefront is plane wavefront.

Diffraction due to a single slit :

[Discuss Fraunhoffer diffraction pattern due to single slit. Obtain expression for minima or maxima]



Consider a plane wavefront incident in slit S_1 , S_2 as shown in figure.

$d \rightarrow width\ of\ the\ slit$

$S_1S_2 \rightarrow slit$

$L \rightarrow convex\ lens$

$D \rightarrow distance\ between\ slit\ \&\ screen$

$f \rightarrow focal\ length\ of\ the\ lens$

$S \rightarrow screen$

$B \rightarrow central\ maxima$

According to Huygen's principle, every point on wavefront acts as a secondary source of light.

Central Maxima (Principle maxima):

Consider a point B at equidistant from S_1 & S_2 on the screen, which lies on the perpendicular bisector of the slit. Thus, the secondary waves from S_1 & S_2 reach the point B in the same phase. Then the constructive interference takes place at B. Therefore, central Bright band is obtained at B, known as central maxima (maximum intensity)

To find path difference : (S_2N) :

Now consider the secondary waves making an angle θ with OB. Let P be the point on the screen at a distance X from central maxima. All the secondary waves meet at point P due to lens. Intensity at P depends on the path difference between the secondary waves originating from the corresponding point of wavefront.

Draw S_1N perpendicular S_2P. The path difference between these waves is S_2N.

$$From\ \Delta S_1NS_2$$

$$\sin\theta = \frac{S_2N}{S_1S_2}$$

$$\therefore S_2N = S_1S_2 \sin\theta$$

$$\therefore path\ difference = d\ sin\theta \qquad |\because S_1S_2 = d\ |$$

Position of first minima :

The path difference = $dsin\theta = \lambda$

The wavefront can be considered to be divided into two equal half OS_1 & OS_2 .

Now the path difference between the secondary waves originating from S_1O is equal to $\lambda/2$. So, these waves will meet at point P in out of phase & hence destructive interference will takes place at point P.

Similarly, the path difference between secondary waves originating from S_2O is $\lambda/2$ & hence these will also produce destructive interference at point P.

$\therefore$ For Ist minima $d\ sin\theta = \lambda$

Position of second minima :

Similarly, for IInd minima

$d\ sin\theta/2 = 2\lambda$

So, for other minima we have,

Path difference = $d\ sin\theta = 2\lambda, 3\lambda$ … … … ..

$\therefore For\ minima,$

$$d \sin\theta_n = n\lambda$$

Where, $\theta_n \rightarrow direction\ of\ n^{th}\ order\ minima$

$n \rightarrow integer = 1,2,3$ … ….

Position of secondary maxima :

It the path difference is an odd multiple of $\lambda/2$, then the constructive inference takes place at point P. Hence point P is the position of secondary maxima.

i.e.$d\ sin\theta_n = (2n+1)\frac{\lambda}{2}$

where n=1,2,3……

where $\theta_n \rightarrow direction\ of\ n^{th}$ order secondary maximum.

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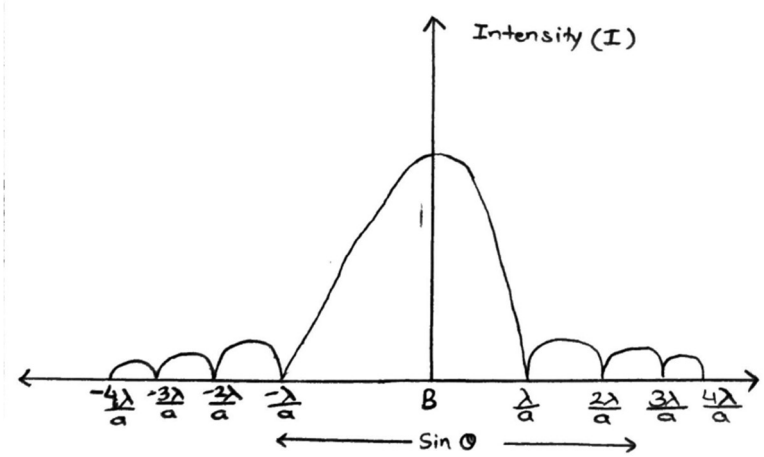
Thus, we see that the diffraction pattern due to single slit consist of a central bright maxima at B followed by secondary minima & maxima on both sides.

Intensity distribution in single slit diffraction :

The variation of intensity with path difference is shown below



The point B corresponds to position of the central bright maxima. The other points on X axis corresponds to point on the screen for which path difference is $\lambda, 2\lambda, 3\lambda$….etc, indicating the position of secondary minima.

The secondary maxima lie midway between secondary minima.

Diffraction between Interference and Diffraction:

Interference	**Diffraction**
1. Interference pattern is obtained due to superposition of waves.	1. Diffraction pattern is obtained due to bending of waves around the edges of an obstacle or a narrow slit.
2. Intensity of all the bright bands remain the same.	2. Intensity of bright bands decreases as we go away from the central maximum.
3. Dark bands are often clear and sharp.	3. Dark bands are generally not so clear and sharp.
4. Bandwidth in the interference pattern due to monochromatic light remains constant.	4. Bandwidth in diffraction pattern never remains constant.
5. Resolving power of optical instrument does not depend upon interference of waves.	5. Resolving power of optical instrument depends upon interference of waves.

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Comparison between Interference and diffraction Patterns

Physical Quantity		Young's double slit interference pattern	Single slit diffraction pattern
For n^{th} bright fringe	Phase difference, δ between extreme rays	$n(2\pi)$	$\left(n+\frac{1}{2}\right)(2\pi)$
	Angular position, θ	$n\left(\frac{\lambda}{d}\right)$	$\left(n+\frac{1}{2}\right)\left(\frac{\lambda}{d}\right)$
	Path difference, Δx between extreme rays	$n\lambda$	$\left(n+\frac{1}{2}\right)\lambda$
	Distance from the central bright spot, y	$n\left(\frac{\lambda D}{d}\right)=nW$	$\left(n+\frac{1}{2}\right)\left(\frac{\lambda D}{d}\right)=nW$
For n^{th} dark fringe	Phase difference, δ between extreme rays	$\left(n-\frac{1}{2}\right)(2\pi)$	$n(2\pi)$
	Angular position, θ	$\left(n-\frac{1}{2}\right)\left(\frac{\lambda}{d}\right)$	$n\left(\frac{\lambda}{d}\right)$
	Path difference, Δx between extreme rays	$\left(n-\frac{1}{2}\right)\lambda$	$n\lambda$
	Distance from the central bright spot, y	$\left(n-\frac{1}{2}\right)\left(\frac{\lambda D}{d}\right)=nW$	$n\left(\frac{\lambda D}{d}\right)=nW$

RESOLVING POWER :

Resolving power of an optical instrument generally depends upon the aperture and the wavelength of the light used.

In general, the resolving ability of an instrument is stated in terms of the visual angle, which is the angle subtended at the eye by the two objects to be resolved. It is the minimum visual angle between two object that can be resolved by that instrument. This minimum angle is called limit of resolution and reciprocal of the limit of resolution is called the resolving power.

Rayleigh's Criterion for Limit of Resolution :

Consider two point objects or two point monochromatic sources of light. If we use two point sources of light we can observe two diffraction pattern on screen.

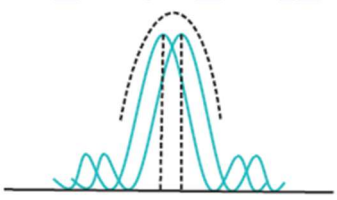


Fig : (a) Unresolved

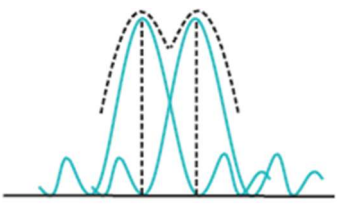


Fig : (b) Just resolved

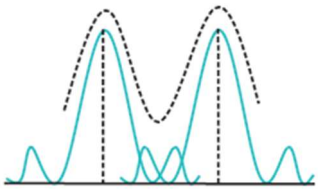


Fig : (c) Well resolved

There are three cases.

1. If two point sources are very close to each other then their diffraction pattern will overlap and there is maximum overlapping. In this case two objects are said to be not resolved i.e. unresolved as shown in fig. (a)

2. If two point objects or sources are widely separated then there will be small overlapping. In this case two objects are said to be well resolved as shown in fig. (c) , fig. (a) and (c) does not satisfy, Rayleigh, criterion.
3. If two point objects or sources are separated such that overlapping satisfies ray leighs criterion such that central maxima of first source falls on first minima of second source and vice versa. In this case two objects are said to be just resolved as shown in fig. (b)

Limit of resolution:

The smallest linear separation or angular separation between two points objects at which they appear to be just resolved is called limit of resolution.

Resolving power:

The reciprocal of the smallest linear or angular separation between two points objects at which they appear to be just resolved is called Resolving power.

$$R.P. = \frac{1}{(\ limit\ of\ \ resolution\ )}$$

i) Two linear objects:

Consider two point objects separated by some distance such that there is overlapping which satisfying Rayleigh criterion i.e. two points objects are said to be just resolved.
The Angular separation of the first minima is,

$$\therefore d\theta = \frac{\lambda}{d}$$

$$\therefore \text{ Limit of resolution } (\ d\theta\ ) = \frac{\lambda}{d}$$

Minimum separation between the two linear objects that are just resolved at distance D is

$$x = D(d\theta) = \frac{D\lambda}{a}$$

ii) Pair of Point objects:

In the case of a microscope quite often, the objects to be viewed are similar to point objects. The diffraction pattern of such objects consists of a central bright disc surrounded by concentric rings, called Airy disc as shown in following figure.

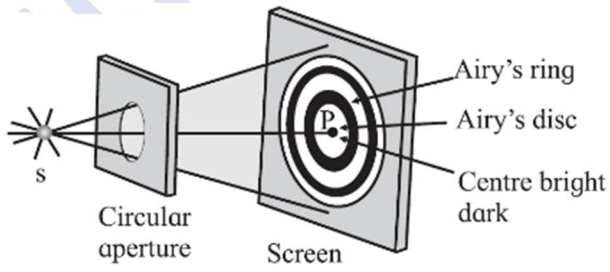


Fig. A schematic diagram showing formation of Airy disc and rings.

Educational Notes

Resolving Power of Microscope:

Consider two point objects O and O' separated by distance a in front of an objective AB of a microscope. Let n be the refractive index of medium between object and objective. λ - be the wavelength. Angular separation between the objects, at the objective is 2α as shown in figure.

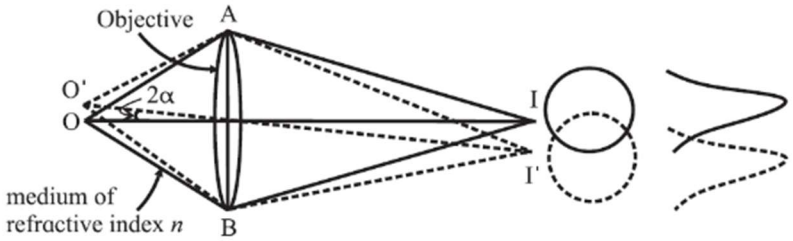


Fig. Resolution of objects by a microscope

i) Microscope with pair of non-luminous objects:

Limit of resolution and Resolving power can be determine as follows :

$$\text{limit of resolution} = \frac{\lambda}{2n\sin\alpha}$$

$$\text{Resolving power} = \frac{2n\sin\alpha}{\lambda}$$

The factor $n\sin\alpha$ is called numerical aperture (NA)

$$\text{R. P.} = \frac{2\,(\text{N. A.})}{\lambda}$$

ii) Microscope with self-luminous point objects:

Applying theory of airy disc, path difference between the extreme rays is 1.22λ

$$\therefore Limit\ of\ resolution = \frac{1.22\,\lambda}{2nsin\,\alpha}$$

$$= \frac{0.61\,\lambda}{nsin\,\alpha}$$

$$\therefore Resolving\ power = \frac{nsin\,\alpha}{0.61\,\lambda}$$

$$= \frac{N.A}{0.61\,\lambda}$$

Resolving Power of a Telescope:

Resolving power of a telescope is defined as the reciprocal of the smallest angular separation between two point objects at which they appear to be just separated when seen through the telescope.

$$Limit\ of\ resolution = \frac{1.22\,\lambda}{D}$$

$$\therefore\ Resolving\ power = \frac{D}{1.22\,\lambda}$$

Where D -is diameter of lens , λ- wavelength

Educational Notes

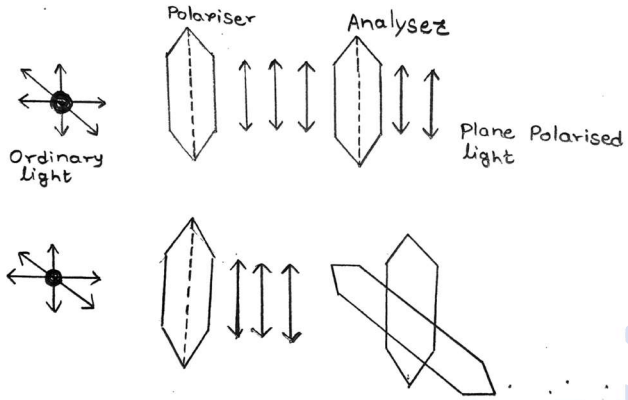
Radio Telescope:

Wavelengths of radio waves are in meter the diameter of radio telescope is very large. In such case arrays of antennas spread over several kilometres . Giant metre wave Radio telescope (GMRT) located at Narayangaon near Pune (MS). It consists of 30 dishes of 45 m diameter each, spread over 25 km. The highest angular resolution achievable ranges from about 60 arcsec at the lowest frequency of 50 MHZ to about 2 arcsec at 1.4 GH_z .

Polarisation Of Light:

The phenomenon due to which the vibrations of light are restricted in a particular plane , is called as polarisation of light.

Explain flow the polarised light is detected by using a tourmaline crystal ?



The tourmaline crystal or Nicol prism used to produce plane polarised light is called polariser. If the polariser is rotated in the path of ordinary light, the intensity of this light transmitted from the polarises remains unchanged.

If the analyser is rotated in the path of the light transmitted from the polariser, so, that the axes of the polariser & the analyser are parallel to each other, then the intensity of light is found to remains unaffected (or maximum), as shown in fig. (a).

On the other hand, the intensity of light becomes minimum, when the axis of the polarises & the analyser are perpendicular to each other. In the positions shown in fig. (a) & (b) , the polariser & the analyser are said to be in crossed positions.

Plane of vibration :

The plane which contains the vibrations of plane polarised light is called plane of vibrations

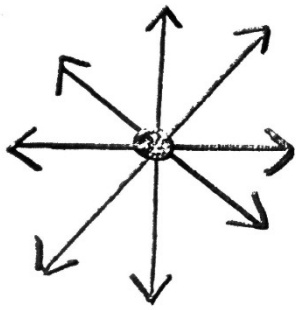
Plane of polarisation :

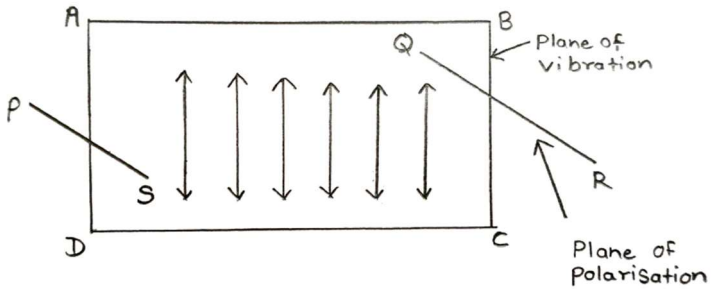
The plane perpendicular to the plane of vibration is called plane of polarisation (PQRS) .

Plane polarised light :

It may be defined as the light, in which the vibrations of the light are restricted to a particular plane.

Educational Notes





Brewster's Law :

[Ques. State & prove Brewster's Law]

Polarising angle (Brewster's angle) : The angle of incidence of ordinary light at which the reflected light from transparent medium is completely plane polarised is called polarising angle.

Statement :

The tangent of the polarising angle of refracting medium is equal to, its refractive index.

Let, $i_p \rightarrow$ polarising angle

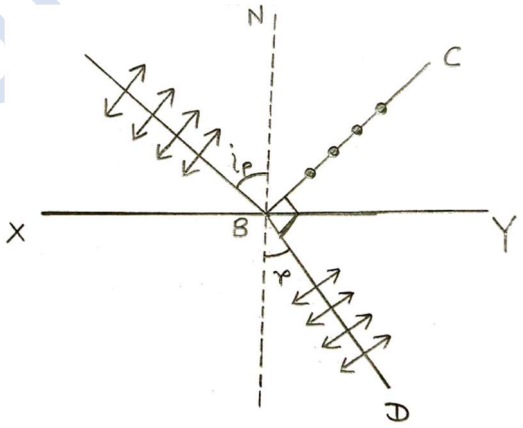
$n \; or \; \mu \rightarrow$ The R. I of the refracting medium

According to Brewster's law,

$\mu = \tan i_p$.....(1)

Proof : Consider a light is incident at polarising angle (P) on transparent media having R.I.μ . The reflected light is found to be completely plane polarised.

By Snell's Law,



$$\mu = \frac{\sin i}{\sin r} = \frac{\sin i_p}{\sin r} \text{ .....(2)}$$

From equation (1) and (2) we have,

$$\frac{\sin i_p}{\sin r} = \tan i_p$$

Or $$\frac{\sin i_p}{\sin r} = \frac{\sin i_p}{\cos i_p}$$

Or $$\frac{1}{\sin r} = \frac{1}{\cos i_p}$$

Or $\sin r = \cos i_p$

$\sin r = \sin(90^0 - i_p)$

$r = 90^0 - i_p$

$r + i_p = 90^o$

Hence when a ray of light is incident at polarising angle, reflected ray is at right angle to the refracted ray.

Equation (2) becomes,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin(90^0 - i_p)}$$

$$\mu = \frac{\sin i_p}{\cos i_p}$$

$\mu = \tan i_p$

Educational Notes

Hence proved.

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